FINDING THE CHANDRA X-RAY OBSERVATORY

The Chandra X-Ray Observatory (CXO) is one of the “Big 4” space telescopes launched by NASA. Designed and constructed to observe x-ray sources, it has produced some of the most beautiful images that cannot be obtained by using visual detectors alone.

Many may not be aware that it is possible for those with telescopes (8-inches or higher) and a relatively sensitive CCD camera to see the CXO and follow it in its orbit, or at least part of it.

This is an account of my first attempt at detecting this unique spacecraft using my CASTOR (Canadian Satellite Tracking and Orbit Research) facility located in Ottawa, Ontario to gauge just how distant an object it could detect.

Figure 1: An artist’s conception of the CXO. Courtesy Harvard/NASA.

AN ECCENTRIC, INCLINED, LONG-PERIOD ORBIT

The CXO was placed in a very eccentric orbit (0.568 to be exact), and orbits the Earth once every 64 hours. Its orbit inclination is about 59 degrees, which is of great advantage to us here in Ottawa, because the satellite can appear at our local zenith.

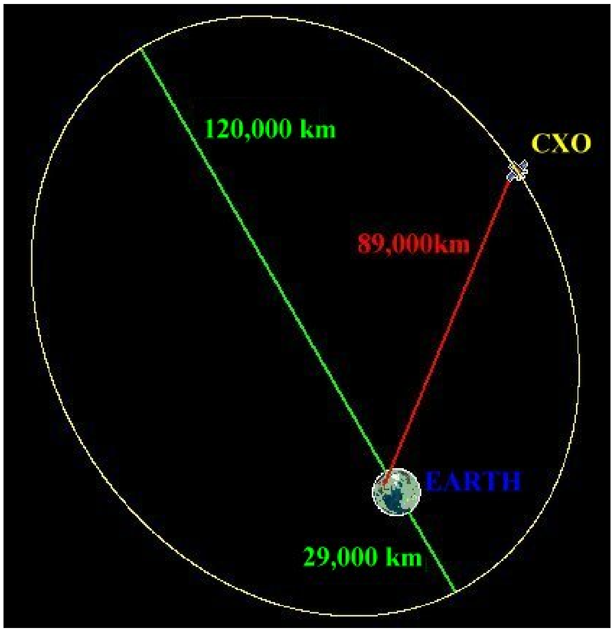

Figure 2: The orbit of the CXO. The planet Earth appears puny in comparison. The total orbit period is 64 hours (2.667 days). The satellite was 89,000 from the CASTOR facility and heading for its apogee when my first attempt to detect it was made.

TOO DISTANT?

A light source will appear one-quarter as bright if placed at twice the distance from the observer, one-ninth as bright when placed at three times the distance, etc. This inverse-square law also applies to a satellite. The reflected light from the CXO can be as close as 29,000km (at perigee) or as far as 120,000km (at apogee) from the Earth, which means that when at apogee, the satellite will appear about 17 times dimmer than it does at perigee. This corresponds to about 3 magnitudes, which might very well mean the difference between detecting it and not detecting it. CCD users: Just think of an 18th magnitude star vs. a 21st magnitude star!

IT'S ONLY A PHASE

You might have noticed that a slim crescent Moon is much dimmer than a full Moon. Phase is determined by the positions of both the observer and the object with respect to the Sun. This includes satellites.

The phase angle is that angle at the object subtended by the observer and the Sun, as shown in Figure 3. When the phase angle is low the satellite will appear at its brightest. When the phase angle is high the observer will only see a small part of the illuminated portion of the satellite, and therefore will have a more difficult time detecting it.

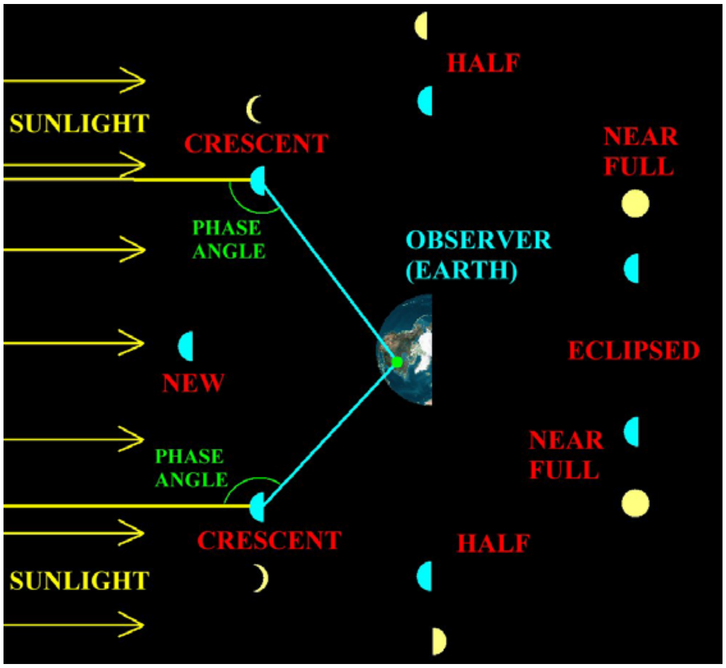

Figure 3: Phase and phase angle of a satellite. For simplicity, it is assumed that the satellite is perfectly spherical. The blue icons show the actual object in space lit by the Sun. The yellow icons illustrate the phase the Earth-bound observer will see given the orientation shown. Note that when the phase angle is around 0, the satellite is eclipsed by the Earth.

The phase (in percent) of the satellite can be calculated from the phase angle using the formula below. This formula can be used for any object whose phase angle is known (this goes for solar system planets too!).

$$\text{Phase (\%)} = 100\% * [\text{cosine(Phase Angle/2)}]^2$$

This formula can easily be used with any simple calculator with trigonometric functions (sine, cosine, tangent etc.).

SPEED KILLS

The problem with imaging satellites with a sidereal drive is that they do not appear to travel at the sidereal rate, as nebulae, galaxies, etc, do. Instead, they will appear to streak across the image, just as stars would if the sidereal tracking were switched off. This means that a longer exposure time will make no difference to the brightness of the satellite on the image, with the possible exception of a higher background noise.

The faster the satellite appears to travel in your local sky, the dimmer it will appear to the CCD camera, since the satellite will travel faster across the pixels, therefore reducing the unit pixel exposure time. You might think of a water-bomber flying over an array of pails. If the bomber flies at 100km/h over the pails as it drops its water, each pail will have a certain amount of water in them. If the same bomber flies at 200km/h over the pails as it releases the same amount of water, there will be less water in the pails than in the 100km/h example.

THE ATTEMPT

On the night of December 6, 2005, I decided to attempt to detect the CXO in Orleans. Right from the start, you might shudder at this prospect, because the sky background can be a large contributor to noise, especially when it is in the form of light pollution from the nearby downtown core and car dealership security lights.

I fired up my Celestron NexStar 11 GPS telescope and ST-9XE CCD camera and proceeded to begin my predictions of where the CXO would appear in my local sky. I found that the CXO was comfortably positioned in the northeastern sky at 56 degrees in altitude, which placed it on the opposite side of the sky from the light pollution in the west. I also found that the CXO was about 89,000km from my location and heading for its apogee. I had no idea if I could detect it at that range.

The satellite's phase angle was about 72 degrees, which translated into a phase of about 65%, which was not great, but not bad either.

CXO's apparent angular velocity as observed from Ottawa was about 3.5 arc-seconds per second at that time. For a 10-second exposure, the satellite would appear to travel just over half an arc-minute across the field of view. Each pixel on my detector covered about 1.56 arc-seconds, but the satellite was not traveling horizontally or vertically across the pixels. I figured that each pixel would be exposing the satellite for about 0.5 seconds, based on the apparent direction the satellite was traveling.

I decided to set my CCD chip temperature to -40C, the coldest I could set it to at the time, so that I could minimize my dark current noise.

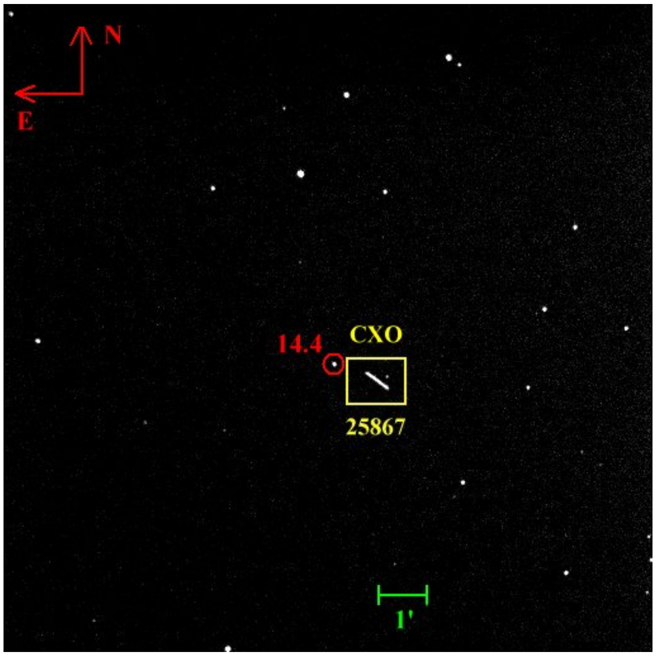

Figure 4: My first image of the CXO (#25867) taken at 07:02:52.67 to 07:03:02.67 U.T.C. on December 6, 2005 (a 10-second exposure). Despite thin cirrus cloud, the object was quite bright, possibly due to a very favorable reflectivity. The photometric benchmark star and its brightness are indicated in red. The FOV of the image is 13.3 by 13.3 arc-minutes.

WAS IT REALLY CXO?

So, was the streak illustrated in Figure 4, really the CXO? Since there are over 10,000 objects orbiting Earth, it might have been another satellite that just happened to drift into my FOV. I checked the following:

i) The apparent angular velocity was predicted to be just over half an arc-minute for a 10-second exposure. The streak length in the image (of 10 seconds) was about 33 arc-seconds, which looked very promising;

ii) The apparent direction of satellite travel was predicted to be approximately North-east. Looking at the image, this also fit the prediction;

iii) About 10 minutes later, I made another prediction and took another image. If the satellite I saw the first time was not the CXO, I shouldn't have seen a streak in the new image. I did see a streak in the new image; and

iv) Just in case, I went through the known satellite catalogue to see if there were any other satellites with a low apparent angular velocity in the general area. There were a few Molniyas (Russian), but they were well out of my FOV and were not traveling in the same apparent direction as the object I had imaged.

Based on the evidence above, I was certain that the streak was indeed the CXO.

BRIGHTNESS ESTIMATION

So, how bright was the CXO when I obtained the image in Figure 4? Using photometric analysis, I estimated that the CXO was at magnitude 12.7 at the time. This was surprisingly bright for a satellite at such a distance and not the best phase angle possible. It might be possible that I was seeing some bright reflection off its solar panels and/or its outer skin.

CONCLUSIONS

The CXO was the first of the NASA big-scale telescopes I was able to detect with CASTOR. The Hubble Space Telescope cannot be detected from Ottawa because it is orbiting at 575km in altitude with a 28.5 degree inclination, which does not take it over Ottawa (not even close). The Compton Gamma Ray Observatory was de-orbited in 2000. The Spitzer Space Telescope orbits in an Earth-following heliocentric orbit.

I felt very fortunate to even catch a glimpse of this remarkable spacecraft. I will be trying to get some more images of it, hopefully at even larger ranges.